

Noninvasive Follow-Up of Coronary Artery Bypass Graft Patency Using Multi-Slice Computed Tomography¹

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Purpose: We wanted to evaluate the utility of multi-slice computerized tomography (MSCT) for assessing coronary artery bypass graft patency and/or occlusion.

Materials and Methods: For 24 patients, both conventional angiography and CT angiography with 4-MSCT were performed within seven days of one another in order to evaluate the accuracy of MSCT with regard to graft patency and/or occlusion. A follow-up CT angiogram was performed in patients with and without symptoms ($n = 11$, $n = 34$, respectively) with 4- or 16-MSCT. We retrospectively compared the results of MSCT to those of conventional coronary graft angiography.

Results: Sixty-five grafts were evaluated for the accuracy of MSCT. Six of those 65 were occluded. The sensitivity, specificity, positive predictive value and negative predictive values of MSCT for the diagnosis of graft occlusion were 100% (6/6), 98% (58/59), 86% (6/7) and 100% (58/58), respectively. Patency could not be determined by angiography in two grafts; however, the grafts proved to be patent on MSCT. On follow-up, new graft occlusions in the asymptomatic patients were detected by MSCT in 8.2% of the previously patent grafts at the two years post-op, and in 15.2% at the three years post-op.

Conclusion: MSCT is a practical and accurate noninvasive diagnostic tool for following up coronary artery bypass grafts.

Index words : Computed tomography (CT)
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Coronary artery bypass graft surgery (CABG) is the treatment of choice for patients suffering with severe obstructive coronary artery disease. The success of the surgery and the rate of patient survival are dependent on graft patency; therefore, post-operative assessment of the bypass graft in the patients who have undergone CABG is very important (1). Conventional coronary artery graft angiography (CAG) is currently the gold standard for assessing bypass graft patency. However, it is an invasive technique and it may cause adverse effects, including arrhythmia, stroke, coronary artery dissection and death. The procedure also incurs a financial commitment, hospital admission and a large measure of patient discomfort (2, 3). Therefore, there is currently a lot of interest in finding a relatively less invasive or non-invasive alternative to CAG. Multi-slice CT (MSCT) has recently been used to determine bypass graft patency and occlusion (4 - 21). Because of the proven accuracy of MSCT, it can be routinely used for post-op follow-up of patients who have undergone coronary artery bypass graft surgery (CABG). We retrospectively reviewed and compared the results of the MSCT and CAG in different situations, including following up during the immediate postoperative period, following up patients with ischemic symptoms after surgery and following up asymptomatic patients. We then analyzed the discrepancies between the two imaging modalities.

Table 1. Demographic Data for the Accuracy of MSCT

	Accuracy of MSCT in Evaluation of Graft Patency	
	Immediate Post-op	Long-term Follow-up
Number of patients	13	11
Gender (male:female)	10:3	6:5
Age (years)	63 ± 6	59 ± 8
CTA-CAG interval (days)	1.8 ± 2.2	2.9 ± 2.2
Postoperative days (years)	5.8 ± 1.7	2064 ± 1594 (5.7 ± 4.4)
Scanners (4-slice:16-slice)	13:0	11:0

Table 2. Demographic Data of the MSCT follow-up Subset of Patients

	MSCT Follow-up		
	With Symptoms	Without Symptoms: First CT	Without Symptoms: Second CT
Number of patients	11	34	12
SexGender(male:female)	6:5	24:10	10:2
Age (years)	61 ± 10	61 ± 8	63 ± 8
CTA-CAG interval (days)	120 ± 97	345 ± 198	619 ± 174
Postoperative days (years)	1434 ± 1757 (3.9 ± 4.8)	695 ± 912 (1.9 ± 2.5)	951 ± 325 (2.6 ± 0.9)
Scanners (4-slice:16-slice)	8:3	28:6	7:5

Materials and Methods

Study Population

We retrospectively enrolled 51 patients (33 males and 18 females, mean age: 61 years) who underwent CTA and at least one CAG after CABG. These patients had a total of 136 grafts, including 73 arterial (54%) and 63 venous grafts (46%). CTA was performed once in 24 patients (55 grafts), twice in 24 patients (74 grafts), and three times in three patients (seven grafts). Therefore, the total number of grafts we evaluated was 224 (81 total CTA scans).

Accuracy of MSCT

For an earlier subset of the study population involving 24 patients (16 males, age: 61.1 ± 7.5 years), both CTA and CAG were performed within seven days (range: 2.3 ± 2.2 days) of one another in order to evaluate the accuracy of CTA (CAG was considered the standard of reference) (Table 1). All the exams were performed using 4-slice CT. For 13 patients, CTA was performed during the immediate postoperative period (postoperative time interval: 5.8 ± 1.7 days). For the other 11 patients, CTA was performed at long-term follow-up (mean: 5.7 years). A total of 65 grafts in 24 patients were evaluated, including 28 saphenous vein grafts (SVG), 22 LITAs, 11 radial artery grafts, three right internal thoracic artery grafts (RITA) and one gastroepiploic artery graft (Table 3).

MSCT Follow-Up

The other subset of the study population involved 45 patients who were referred for CTA follow-up to evaluate their graft patency, and they had undergone CAG at least once either before or after MSCT with more than a one month time interval (Table 2). For the patients who had multiple CAG examinations, the data from the most contemporary CAG was used. Of this MSCT follow-up group, 11 patients (31 total grafts) with persistent chest discomfort underwent CAG to confirm the CTA results.

The other 34 patients (93 grafts), who did not experience any chest symptoms, were also enrolled and they received follow-up CTA. Twelve of these 34 patients (35 total grafts) underwent another CTA approximately one year later. Information about these subjects is summarized in Tables 2 and 3. During the follow-up period when we used CTA, a 16-slice CT was installed in the institute and this was then used to determine post-op graft patency. The hospital ethics committee approved this protocol, and all the patients gave us and informed consent.

Multi-slice CT: Graft Angiography Protocol

CTA scans were performed using a 4-slice CT scanner (LightSpeed Plus, GE Medical Systems, Milwaukee, Wisconsin, U.S.A.) or 16-slice CT scanner (Sensation 16, Siemens, Forchheim, Germany). We did not pre-medicate any of the patients.

Protocol for 4-slice CT

The scan range was adjusted to cover all the grafts, from the uppermost implanted graft vessel at the ascending aorta to the diaphragmatic surface. For the case of the patient with a gastroepiploic artery graft, the scan range was extended lower to include the pancreas. Prior to the CTA scan, the patients were injected with a 15-ml

bolus injection of non-ionic contrast agent (370 iodine mg/mL, Iopamiro; Bracco, Milan, Italy) in order to measure the circulation time. The scan delay was set at five seconds after the time of peak enhancement of the ascending aorta. The CTA scan was performed in a cranio-caudal manner. The gantry rotation time was 500 ms, and the tube current was 270 - 300 mA at 120 kV. The breath-holding time, which depended on the patient's heart rate and the anatomic coverage, ranged from 25 to 40 seconds. Pitch also depended on the patient's heart rate at the beginning of the scan or the heart rate that was input by the operator, which was adjusted automatically in increments of 0.1 according to the preprogrammed manufacturer settings within a range of 1.0 - 4.0. For imaging in a patient with a heart rate that varied from 45 to 75 beats per minute, the pitch varied from 1.2 to 1.5. The total CTA scan contrast dose ranged from 120 - 180 mL, and this depended on the total scan time. The patients received the contrast agent through an 18-gauge needle in the antecubital vein, and they were injected at a rate of 4 mL/s for the first half of the total scan time, and at 2 mL/s for the second half.

Protocol for 16-slice CT

A real-time bolus tracking technique was used in order to trigger the scan. The scan delay was set at six sec-

Table 3. Number of Grafts in Each Subset of Patients

	Accuracy of MSCT in Evaluation of Graft Patency		MSCT Follow-up		
	Immediate Post-op	Long-term Follow-up	With Symptoms	Without Symptoms : First CT	Without Symptoms : Second CT
All grafts	36	29	31	93	35
LITA*	13 (36)	9 (31)	10 (32)	34 (37)	12 (34)
RITA [†]	3 (8)	0	0	2 (2)	0
RA [‡]	8 (22)	3 (10)	0	20 (22)	6 (17)
GEA [§]	1 (3)	0	0	1 (1)	0
SVG**	11 (31)	17 (59)	21 (68)	36 (39)	17 (49)
Occlusion on CAG	0	8 ^{††} (28)	9 (29)	8 (9)	2 (6)
Occlusion on CTA	0	6	9 (29)	15 (16)	7
Occlusion only on CAG	0	2 ^{‡‡}	0	0	0
Occlusion only on CTA	0	1 ^{§§}	0	7 ^{***}	5 ^{†††}

*. Left internal thoracic artery graft

[†]. Right internal thoracic artery graft

[‡]. Radial artery graft

[§]. Gastroepiploic artery graft

** . Saphenous vein graft

^{††} . Including two grafts that were not diagnosed due to the lack of selective angiography

^{‡‡} . Two grafts that were not diagnosed due to lack of selective angiography

^{§§} . A case with competitive flow

^{***} . Newly developed occlusion on CTA

^{†††} . Newly developed occlusion on CTA

: The number in parentheses is the percentage in each subset of patients.

onds after the enhancement of the ascending aorta reached 100 HU. The CT parameters were as follows: 12×0.75 mm collimation, 0.42-seconds rotation speed, 500 effective mA at 120 kV and 2.7 mm/rotation table-feed. The amount of nonionic contrast agent (370 iodine mg/mL, Iopamiro; Bracco, Milan, Italy) ranged from 100 to 140 mL, and it was injected during a single inspiratory breath-hold (duration: 24.2 ± 3.4 s) via an 18- or 20-gauge needle through an antecubital vein (flow rate: 4 mL/s). A multi-cyclic, segmented reconstruction algorithm was used. The temporal resolution was from 110 to 210 ms. Radiation dose modulation was not used because the images should be reconstructed not only at a diastolic phase, but also at a systolic phase to obtain better qualities. The other, unmentioned protocol details were essentially the same as those for 4-slice CT.

Multi-slice CT: Reconstruction and Interpretation

With using the 4-slice CT scans, the axial image data sets were reconstructed with a 1.25-mm thickness and a 1.0-mm increment by using retrospective ECG gating at 40% and 70% of the cardiac cycle (the R wave-to-R wave interval). With using the 16-slice CT scans, axial image data sets were reconstructed with 1.0-mm thickness and a 0.5-mm increment at one or two cardiac phases, which were selected by using the preview reconstruction function, where the phase had the least motion artifacts. On the basis of the reconstructed data sets, the three-dimensional volume rendered images, the thin or thick slab of maximal intensity projection images and the curved multi-planar reformatted images were reconstructed for each bypass graft on an off-line workstation. Two radiologists, who were unaware of the invasive coronary arteriography outcomes, evaluated all the CT data by working in consensus. The bypass grafts were considered occluded if they showed no contrast material filling on any images, or if they showed only a short segment of contrast material in the proximal stump. Otherwise, the grafts were considered patent.

Conventional Graft Angiography

Bypass graft contrast angiography was performed using a digital angiographic system (Hicor, Siemens, Erlangen, Germany). Every graft was selectively catheterized for performing selective angiography. However, some composite grafts could not be directly catheterized due to an anastomosis with the distal part of another graft. In that case, indirect angiography was

completed with a proximal injection into the other graft. In some patients with a left internal thoracic artery graft (LITA), left subclavian arteriography was performed in place of selective graft angiography. Non-visualization of the contrast agent into the grafts was considered to be an occlusion. Failure to cannulate a targeted graft from the aorta, without any evidence of contrast filling according to the aortography, was tentatively considered to be an occlusion of the graft as well.

Data Analysis

The results from CAG served as the standard of reference. The bypass graft patency diagnostic accuracy of CTA was expressed as the sensitivity, specificity and the positive and negative predictive values. Any discrepancies between CTA and CAG were analyzed.

Results

Accuracy of MSCT

In 13 patients, no grafts were occluded in the immediate postoperative period. CAG showed occlusion of eight grafts in 11 patients in the long-term follow-up group. CTA correctly diagnosed six of these occlusions, including four SVGs and two radial artery grafts. The remaining two grafts were diagnosed as being patent on CTA. These grafts entailed a SVG connected from the aorta to the first obtuse marginal branch (Fig. 1), and a SVG connected from another graft (Fig. 2). Upon review of these cases, there was no doubt that the grafts were patent on CTA, as there was a continuous, strong opacification of the lumen with contrast material. Upon examining the CAG, we concluded that the two cases had been tentatively diagnosed as occluded because the grafts could not be visualized. The selective angiography failed because a surgically placed metal indicator was not present for the graft in the former case and the composite graft was distally connected from another graft in the latter case.

There was only one false positive case, in which the CTA showed no opacification of a LITA connected to the middle segment of the left anterior descending artery. We noticed that the graft was patent, but it had competitive flow on angiography. The sensitivity, specificity, positive predictive value, negative predictive value and accuracy were 75% (6/8), 98% (56/57), 86% (6/7), 97% (56/58) and 95% (63/65). Graft occlusion was determined to be 9% (6/65) of the grafts, including 2 ambiguous cases that were tentatively diagnosed as occluded on

CAG. The sensitivity, specificity, positive predictive value and negative predictive value were 100% (6/6), 98% (58/59), 86% (6/7) and 100% (58/58), respectively. Overall accuracy was 98% (64/65).

MSCT Follow-Up

The CTA and CAG results were concordant for 31 grafts (11 patients) in those patients with ischemic symptoms. These results included the detection of nine occluded grafts (29%). Two (20%) of the 10 LITAs and sev-



Fig. 1. 59-year-old male patient. A volume rendered image with a superior view (A) and an axial image (B) of the contrast-enhanced CT angiography both reveal a patent saphenous vein graft. The patient underwent surgery eleven years prior. The graft coursed posterior to the aorta, without a metal indicator at the proximal anastomosis. The selective angiography failed, and the graft was not visualized by aortic root angiography (not shown).

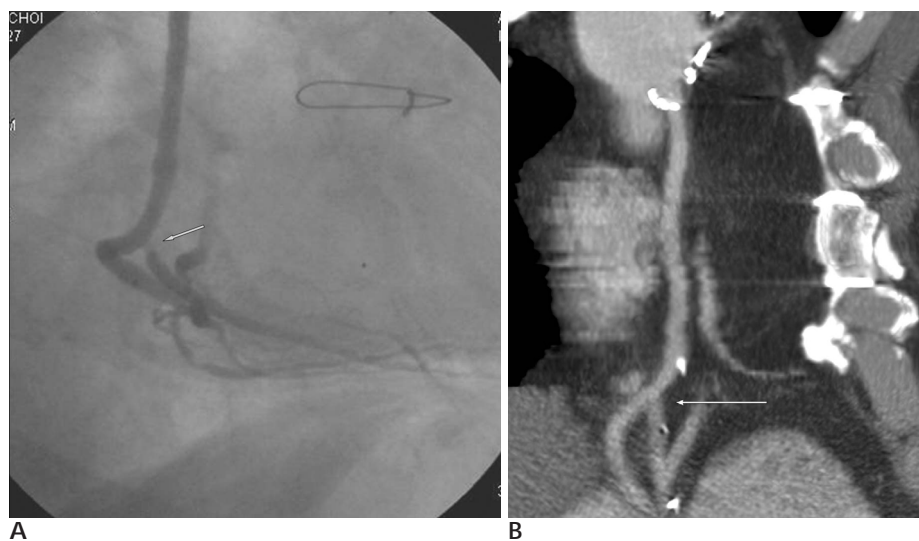
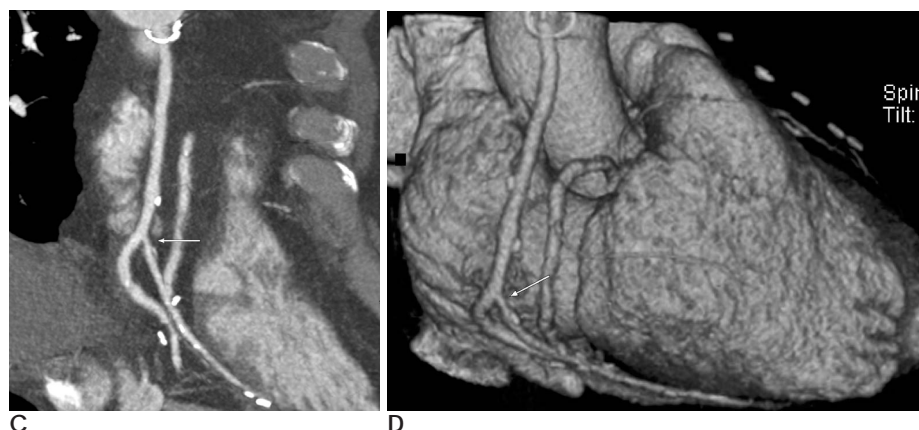


Fig. 2. 64-year-old male patient. On the 1-year follow-up angiography after surgery (A), the catheter tip is located at the proximal SVG and the contrast agent is injected. The SVG connected from another SVG is visualized only by the slow retrograde filling (arrow), which does not reach the proximal anastomosis. Seven days later, CTA (B) shows the graft patent. Two years later, the follow-up curved MPR CT image (C) and the volume rendered image (D) confirm the patency of the graft. The patient had reported no symptom.



en (33%) of the 21 SVGs were occluded. For 93 grafts (34 asymptomatic patients), CAG demonstrated eight occluded grafts (8.6%). The following CTA revealed seven more occluded grafts, which was 8.2% of the 85 patent grafts on the previous CAG. Therefore, there was a total of 15 occluded grafts detected on CTA (16%) (Table 4). In 12 patients, the second follow-up CTA was performed within 347 ± 128 days after the first CTA and it revealed five more graft occlusions (15.2% of the 33 originally patent grafts). Newly observed occlusions were found in two of the 11 previously patent LITAs (18%), and also in three of the six previously patent radial artery grafts (50%). All the occluded radial artery grafts were composite grafts.

Discussion

Even though single-slice CT was not sensitive detecting for graft occlusion, it could detect graft patency.

However, both 4- and 16-slice CT can be used for the detection of both graft occlusion and patency (4). With the introduction of 4-detector CT into clinical practice, the sensitivity (93 - 100%) and specificity (97.8 - 100%) of CT for detecting patency or occlusion has increased (5 - 10). Compared to a 4-slice CT, the 16-slice CT demonstrated a significantly better image quality, regardless of the type of graft, for all bypass segments, with the exception of distal anastomosis (11). The accuracy of a 16-slice CT for the diagnosis of graft patency has slightly improved as compared to that of the 4-slice CT; 16 slice CT demonstrating a sensitivity of 96 - 100% and a specificity of 93 - 100% (12 - 17).

In the present study, the accuracy for diagnosing graft patency and occlusion with using 4-slice CT was 98%. This percentage is considered to be relatively high as compared to the previous studies, even though no blockers were used and no cases were excluded from this study. Graft patency could be determined by

Table 4. Follow-up MSCT in the Patients Without Symptoms

	Without symptoms			
	CAG	CTA	Only on CAG	Only on CTA (New)
Occluded grafts	8/93 (8.6)	15/93 (16)	0	7/85 (8.2)
LITA*	1/34 (2.9)	3/34 (8.8)	0	2/33 (6)
RITA [†]	0/2 (0)	0/2 (0)	0	0/2 (0)
RA [‡]	2/20 (10)	6/20 (30)	0	4/18 (22.2)
GEA [§]	0/1 (0)	0/1 (0)	0	0/1 (0)
SVG**	5/36 (13.9)	6/36 (16.7)	0	1/31 (3.2)

*. Left internal thoracic artery graft

[†]. Right internal thoracic artery graft

[‡]. Radial artery graft

[§]. Gastroepiploic artery graft

** . Saphenous vein graft

: The number in parentheses is the percentage in each subset.



Fig. 3. 54-year-old male patient. The one week follow-up angiography after surgery (A) shows the left internal thoracic artery graft and the radial artery composite graft are both patent. The two-year follow-up CT angiography (B) shows the two grafts are patent, which is well correlated with the previous angiography.

demonstrating at least two different levels of the contrast-filled graft lumen (22). Therefore, motion artifacts or metal artifacts (i.e., that resulted from clips obscuring some segments of grafts) did not necessarily reduce the accuracy of MSCT. In this study, no case of graft occlusion showed any additional patent segments or a patent proximal segment that was longer than 15 mm.

Graft patency could not be determined when selective graft angiography was not performed: this was caused by the limited accessibility of complex composite grafts or by grafts without metallic markers (10). In this case, MSCT accurately demonstrated patency or occlusion, and this is an advantage of MSCT over conventional graft angiography. In the presence of competitive flow in a graft, effective lumen contrast-filling may not be possible and MSCT may incorrectly diagnose the physically patent graft as being occluded. This was the only incidence of false graft patency interpretation in our study. Therefore, readers of CTA scans should be aware of this possibility when determining the presence of an occlusion.

MSCT was very effective and accurate for following up graft patency during the post-CABG period for both symptomatic and asymptomatic patients (Fig. 3). Examining the immediate postoperative graft patency is important because early occlusion may occur within the first week to month (a 10% likelihood in SVGs, 1% in LITA, 6% in RITA and 4 - 10% of radial grafts) and this is mainly due to spasm (23). Determining the etiology of ischemic symptoms after bypass graft surgery is an important clinical issue and it is essential for delivering proper management. The cause of recurrent chest pain varies with the time after surgery. When symptoms are first noted in the immediate postoperative period, it may be due to a technical problem with a graft or with early graft closure; these are not reliably detected with MRI (24). In our study, all grafts in the patients that were followed during the immediate postoperative period were patent on CAG and MSCT. After the first few postoperative months, the symptoms are usually caused by both graft problems and by the progression of atherosclerosis in the non-bypassed vessels. For the symptomatic patients after bypass grafting, the angiographic graft failure rate is approximately double that in the patients without symptoms, which was compatible to the high occlusion rate of the symptomatic group (29%) in this study (25). Although the time interval between CTA and CAG for the symptomatic patients was about six months, the MSCT results were the same as those for

the CAG in all cases. MSCT was very sensitive for detecting newly developed graft failure in the patients without symptoms. This implies that many patients with newly developed graft failure do not present with symptoms.

Off-pump coronary artery bypass grafting (OPCAB) combined with the aorta no-touch technique has been accepted as an effective procedure to avoid neurologic and aortic complications, and also to reduce the operative risks (26). Using the radial artery for a composite graft in context of the no-touch aorta technique has been well documented. However, the long-term patency of a radial artery composite graft has not been fully studied. In the present study, the high occlusion rate of the radial artery graft on the first or second follow-up CTA reflected the increased use of radial artery composite grafts with the OPCAB technique at our institute. This result demonstrated that MSCT could be used as a noninvasive modality for evaluating new bypass grafting techniques.

Graft stenosis was not evaluated with MSCT in this study. The image quality was not sufficient to diagnose graft stenosis, primarily because we did not use a β -blocker to control the heart rate, nor did we exclude any candidates with coexisting arrhythmia or tachycardia. We also did not exclude any cases with severe post-scan motion artifacts. MSCT has a limitation to functionally assess graft flow. Even though the study population and the CTA protocols were heterogeneous, and the time interval between the two modalities was variable, the results of this study showed the usefulness of MSCT in daily practice for a variety of situations.

In conclusion, in terms of patency and occlusion as compared to conventional invasive angiography, 4- or a 16-slice MSCT is a very practical, highly accurate, and reproducible noninvasive tool for evaluating coronary artery grafts during both the immediate postoperative period and on the long-term follow-up, and this is regardless of the patient's symptoms or heart rate.

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